CORRELATES OF THE TACTUAL AND KINESTHETIC STIMULI IN THE BLIND MAN's CANE

Leonard Potash

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CORRELATES OF THE TACTUAL AND KINESTHETIC
STIMULI IN THE BLIND MAN'S CANE

by

LEONARD POTASH
B.S.M.E., University of Nebraska
(1949)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
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at the

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June, 1961

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Department of Mechanical Engineering, June, 1961

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Thesis Supervisor

Accepted by ______________________________
Chairman, Departmental Committee on Graduate Students

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CORRELATES OF THE TACTUAL AND KINESTHETIC STIMULI IN THE BLIND MAN'S CANE

by

Leonard Potash

Submitted to the Department of Mechanical Engineering on May 26, 1961 in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

The cane is the device used almost universally by the blind for mobility and orientation. The precise reason has never been investigated. Therefore, this experiment has been designed to study the mechanical interactions between a blind man and his environment through the medium of the cane.

Preliminary experimentation indicated that force and displacement were the two principal correlates to be studied. Consequently, force discrimination thresholds were measured by the psychophysical method of jnd's (just noticeable differences) and the displacement discrimination level of a blind man with a cane was established by the "fractionation" method.

The tests definitely indicated that force discrimination with the cane is not a significant function of the cane stiffness over a wide compliance range.

The numerical results of the experiment may be used for comparison with subsequent studies; and for the present may be used as two of the performance parameters of the cane-man system.

Thesis Supervisor: Thomas B. Sheridan
Assistant Professor of Mechanical Engineering

ACKNOWLEDGEMENTS

To my mentor, Professor Thomas Sheridan, go both my gratitude and appreciation for his help and guidance through this initial investigation.

To my colleagues in Dynamic Analysis and Control Laboratory go my thanks for their kind toleration and ready assistance.

Last, though certainly not least, to my wonderful wife who has patiently kept our home and family in California functioning during this dislocation, I am especially grateful.

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TABLE OF CONTENTS

Page

Abstract ii

Acknowledgements iii

INTRODUCTION 1

Literature Review 2

DESIGN OF THE EXPERIMENT 5

Preliminary Experiment 5

Final Experimental Design 9

Displacement Discrimination Test 17

TEST APPARATUS 20

Subjects 20

Test Specimen 20

Variable K Spring and Deflection Micrometer 21

EXPERIMENTAL RESULTS 27

Force Test Discussion 27

Force Test Conclusions 34

Displacement Test Discussion 35

Displacement Test Conclusions 36

Future Investigations 37

Application of Conclusions 38

Appendix A - jnd Computation Methods 41

Appendix B - Springs-in-Series Effect 43

Appendix C - Distance Discrimination Computation Methods 44

Bibliography 45

INTRODUCTION

Perhaps one of the greatest problems confronting the blind is the ability to move about in a sighted world without the aid of a sighted guide. The two aspects of this problem are:

1. Mobility, or piloting, i.e., the avoidance of objects;
2. Orientation, or navigation, i.e., the control of one's motions by the recognition of objects. (K.S. Lashley in ref. 2)

In general the auditory sense becomes the blind man's principal modality for mobility and orientation. The so-called "obstacle sense" of the blind man has been independently shown to be a function of normal, but acutely trained, audition (6,7, 8)*. However, in a significant number of circumstances, one's hearing must be reenforced by the somesthetic senses since extraneous noises can mask auditory cues. In addition, there are a great many obstacles to mobility which offer no auditory cues. It is to the detection of these obstacles that a great deal of research has been devoted during the past twelve years (9). In spite of several electronic obstacle detectors (10,11) which have been developed during this time the cane still remains the single artificial inanimate device used almost universally by the blind for mobility and orientation. Precisely why the cane is most satisfactory has never been established and a survey of the

---

*Numbers in parentheses refer to the bibliography.

literature reveals no specific study toward this end. Therefore, on the hypothesis that there are mechanical interactions between a blind man and his environment through the medium of the cane, this study has been initiated to determine the nature and magnitude of these interactions.

Literature Review

It is essential that the researcher in sensory aids for the blind gain a comprehensive knowledge of blind sociology and psychology before any attempt can be made to scrutinize one isolated facet. Lende's bibliography provides general references about blind problems (5).

For foot travel aids, several sources (9,10,12,13) discuss specific requirements for mobility and orientation, while others (1,2,13) mention requirements for a cane in particular.

Arnold Auch (12) gives the following requirements for foot travel by the blind:

1. Following an obstruction line (a wall, fence, or shrub).
2. Walking in a straight line.
3. Detection of obstacles from the ground up, and also suspended obstructions such as tree branches.
4. Finding objects of curiosity and check points.
5. Detection of drop-offs and step-downs.
6. Travelling in snow; snow is "blind man's fog" due to absorption of virtually all sound.

The exact mechanism by which a cane or any other device can

satisfy all, or even the major part of these requirements, is not explained in any of the references. However Levy (1), in 1872, mentions "this (stick) should be light and not elastic, in order that correct impressions may be transmitted from the objects with which it comes in contact to the hand of the user", "the stick is not only to discover the nature of the ground but also to defend the walker from objects at rest".

Immediately after World War II, R.E. Hoover (2) studied the mobility problem of blind veterans and devised a standard technique for the use of the cane. He theorized that the cane is primarily a bumper, and secondarily a probe. Consequently he developed, as part of the technique, the "long cane". This cane or a modification of it is used, along with the Hoover technique, in almost every blind rehabilitation center. The cane is described in detail in the section on test apparatus, but briefly it is an aluminum tube, $\frac{1}{2}$ in. diameter, about 4 ft. long and tipped with a steel ferrule; the handle is a 4 in. crook. The Hoover technique for foot travel consists of sweeping the cane in rhythm with the gait and tapping the tip of the cane to the ground at the extremity of each arc so that any surface irregularities will be detected at the borders of the path width sufficiently wide to pass the traveller. The sweep of the cane provides continuous bumper duty for detection of ground obstacles while the tap of the cane one step ahead of the leading foot gives a sampled-data probe for step-downs. The

salient feature of this technique is that the cane's most important function is the detection of step-downs and drop-offs. These indeed appear to be the greatest of stationary hazards to the blind. In fact several blind travelers (13,14) have advocated that the cane tip not be tapped at every step but, instead, be allowed to glide continuously over the terrain, particularly over unfamiliar ground, so that step-down information is continuous. Similarly, "shorelining", i.e., following an obstruction line such as a curb or lawn edge, must also be done on continuous contact basis unless roughness of the surface precludes this.

This brief review of foot travel, in general, and cane attributes and techniques, in particular, represents the significant thoughts and works done by workers for the blind in defining the task of the cane in mobility and orientation. Clearly, the cane must allow the blind man to study the geometry of his environment as well as to detect objects whose location, if hazardous, must be known.

Working in a somewhat similar area - determination of factors influencing proprioceptive feedback in aircraft control stick movements - experimental psychologists provide some references for the determination of the mechanics involved in accomplishing the task of the cane. These references will be discussed in connection with the design of this experiment.

DESIGN OF THE EXPERIMENT

Preliminary Experiment

In the beginning, these questions presented themselves:

1. How does one break the man-machine loop comprising the blind man and his environment in order to study interactions along one path - the cane?
2. What variables does the sightless man receive, consciously or unconsciously, while probing his environment for recognition of its pattern?
3. What are the magnitudes of these variables?
4. If the answer to question 2 can be assumed for a first approximation, how can the minimum useable magnitudes of the variables be determined?
5. Can the answers to questions 3 and 4 be used to arrive at a mechanical impedance match between the environment and the man, using the cane as the matching device; or from the engineering viewpoint, can the design of a cane be optimized for convenience [Hoover in (2)] without serious mechanical impedance mismatch?

Breaking the loop in question 1 is basically a neurological problem since the loop elements are not in cascade; e.g. a man cannot detect cutaneous pressure in his palm until he exerts a compression on the cane, therefore his response is a function of his exertion. However, it is possible to assume the interactions -

the variables of question 2 - and selectively filter them while the blind-man machine system is in operation. This was accomplished by first assuming that the mechanical interactions between the blind man and his environment, for purposes of mobility and orientation, are: force, displacement, vibration and sound. Then a course, a long hallway containing normal obstacles, was traversed for a performance rating. The performance criterion was the inverse of time required to traverse the course. Several traverses were made during each of which the subject's aural channel was jammed by the use of white noise in a set of soundproof earphones which he wore. During the first traverse, a normal long cane was used and the subject showed no significant variations from his normal mode other than a slight meandering of course due to deprivation of his audio cues (15). For the next traverse, a force-free cane, Fig. 1, was used. This cane was a conventional long cane in which the shaft had been cut and a universal joint inserted at the cut. The resulting removal of virtually all force transmission from the cane input at the tip, to the output at the handle, rendered the subject completely disoriented since his geometry input appeared to have vanished with the force removal. The last traverse was made with a vibration damped cane in which a normal long cane shaft had been cut and a soft rubber hose inserted to separate the two pieces of tubing. The results of this traverse were extremely interesting. The sweep of the cane was naturally somewhat erratic since the greatly reduced stiff-

DEPTH FRACTIONATION

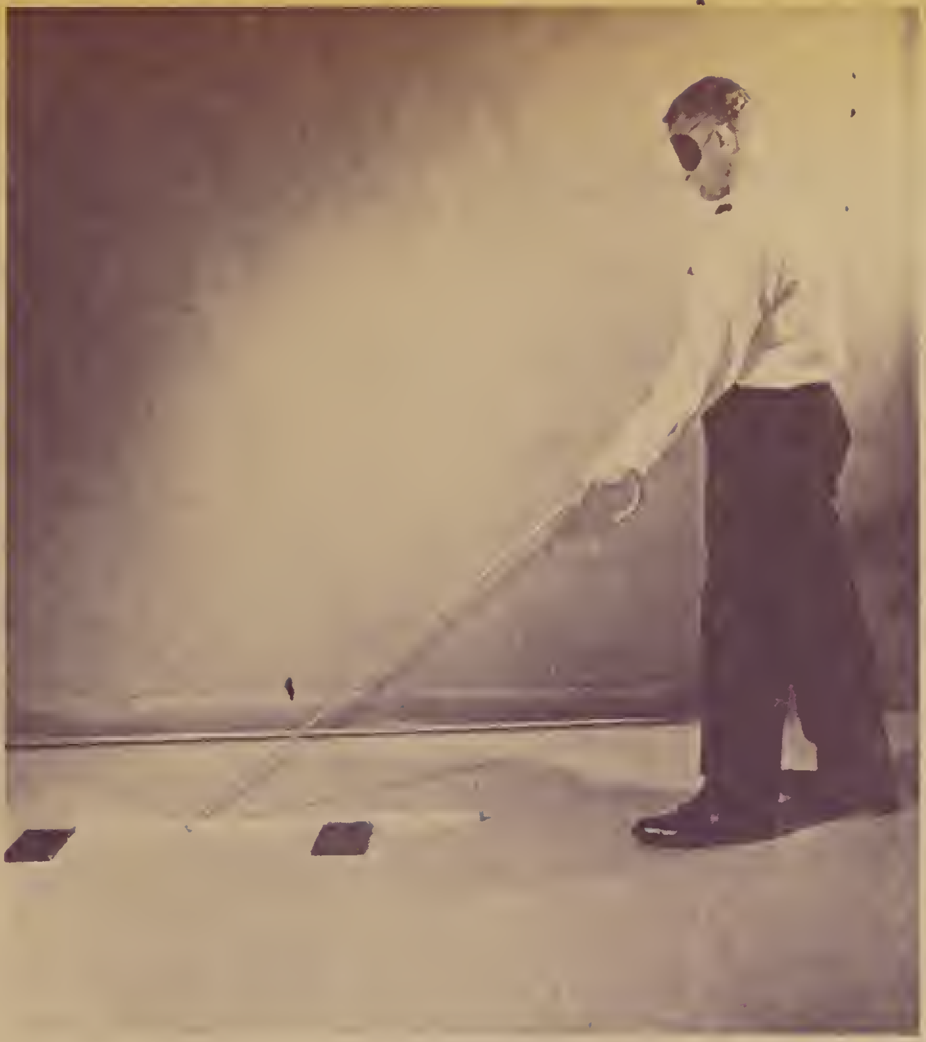


FIG. 2

FORCE - FREE CANE TRAVERSE

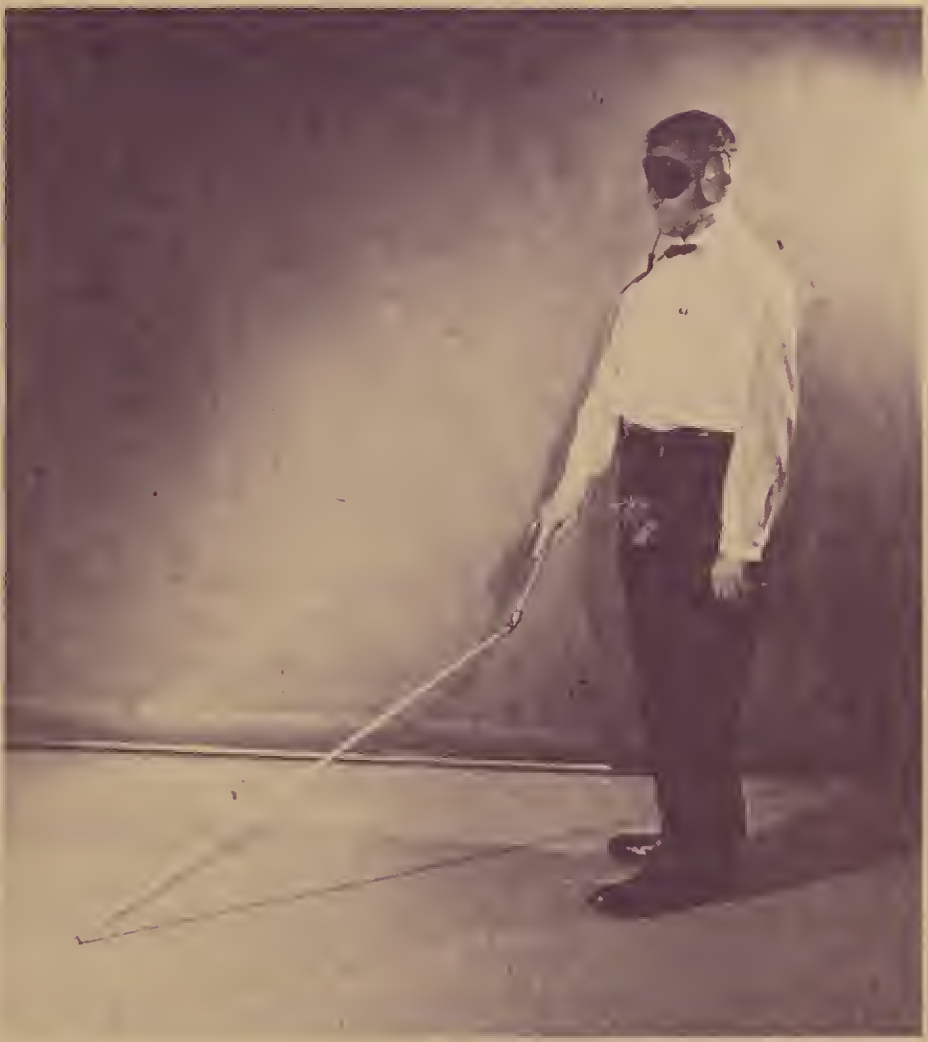


FIG. 1

ment caused the cane lateral motion to become uncoupled from the subject's sweeping motion, the normal sweep rate of which far exceeded the extremely low natural frequency of this modified cane. None-the-less the subject was able to traverse the course in almost the same time as with the normal cane. Furthermore, when the gliding tip technique [14] was employed rather than the tapping method of Hoover, step-downs were detected as readily as with the normal cane whose stiffness exceeded that of the vibration-free cane by more than an order of magnitude. This can best be explained by observing that the vibration-free cane did not completely block vibration but simply greatly attenuated the vibration displacement; however since the vibration displacement sensitivity is high [4,16] at the palm of the hand - motions of 10 microns may be detected - there was sufficient amplitude of vibration coming through the dampener to excite a response in the subject. As soon as the gliding tip slid over the step-down ledge, the subject stopped in the same manner as if he was using the normal long cane. Further increase of the low frequency damping of the cane did not increase the traverse time.

As a result of these modified cane traverses, the following conclusion was inferred: those mechanical interactions between a blind man and his environment, which most grossly affect his mobility and orientation performance with the cane, i.e., his geometric discrimination, are *time-variant forces* such as vibrations and impulses, and *spatial-dependent forces* such as the forces complementing displacement and angle changes which the

blind detect while "shore-lining".

Admittedly the above conclusion is partly a prediction based on an assumption and demonstrated qualitatively by a non-rigorous method. However, it serves well as a first approximation in the solution of this untried problem. A group of workers, under Professor T.B. Sheridan, is at present attempting to answer questions 2 and 3 using strain-gage instrumented canes. Their results will appear in a later publication.

The results of the traverse experiments were used to answer question 4 which served as a vehicle for the final design of this experiment, i.e., a quantitative study of the correlates - force and displacement - of the tactile-kinesthetic stimuli. A study of the force and time dimensions of the tactile-kinesthetic stimuli could be done to establish the minimum vibration levels necessary to produce a response in the blind man; but several studies (4,17,18) indicate, in agreement with the forementioned vibration-free traverse, that a human is sufficiently sensitive to the vibration stimulus that there is virtually no subliminal level greater than zero that can be measured.

Final Experimental Design

The final design of this experiment, then, was to provide a study of the forces and displacements which a sightless person can detect through the use of a cane. The philosophy of the design was to maximize simplicity and reliability of method and apparatus.

Nothing more sophisticated than the conventional psychophysical methods of differential threshold determinations were used in the study of the ability of the blind to discriminate forces. See Table 1, pages 11-13. Basically, the test was a measure of the force resolution of the man using the cane. There was little precedence to follow in using this method of jnd's (just noticeable differences) though one experimenter in aircraft control man-machine systems did use this method (22).

The test apparatus, which will be described in the next section, provided a convenient, accurate, and reliable method of rapidly offering the subject a reference force R and then a comparison force C where

$$C = R + \Delta R \quad \text{and} \quad 2\% < \frac{\Delta R}{R} < 32\%.$$

The reference force R was obtained by the combination of a CONSTANT and a REFERENCE where the CONSTANT was a spring constant K and the REFERENCE was a deflection δ or else the CONSTANT was a deflection δ and the REFERENCE was a spring constant K.

The comparison force C was obtained by changing the REFERENCE by a small ± increment ΔR from its reference force position while the CONSTANT remained at its same setting.

In the $\frac{\Delta \delta}{\delta}$ Variable Treatments, see Table 1, the ΔR was derived from maintaining the spring constant K of a variable K spring at a CONSTANT level and varying the REFERENCE deflection δ

Table 1

Experimental Design

Force Discrimination Tests

10 lb. Compression

Variable Treatment		$\frac{\Delta\delta}{\delta}$				$\frac{\Delta K}{K}$				Control Treatment $\frac{\Delta K}{K}$ NoStop			
REFERENCE R		1.0 in	0.5 in	0.2 in	0.1 in	10 lb/in	20 lb/in	50 lb/in	100 lb/in	10 lb/in	20 lb/in	50 lb/in	100 lb/in
CONSTANT		10	20	50	100	1.0 in	0.5 in	0.2 in	0.1 in	—			
Subject	ΔR %	—				—				—			
1	2												
	4												
	8												
	16												
	32												
2	2												
	4												
	8												
	16												
	32												
3	2												
	4												
	8												
	16												
	32												
4	2												
	4												
	8												
	16												
	32												

Note: Each block contains % correct of 20 discriminations

Table 1

Experimental Design

Force Discrimination Tests

1.0 lb. Compression

Variable Treatment		$\frac{\Delta\delta}{\delta}$				$\frac{\Delta K}{K}$				$\frac{\Delta K}{K}$ No Stop			
REFERENCE R		0.8 in	0.4 in	0.2 in	0.1 in	1.25 lb/in	2.5 lb/in	5 lb/in	10 lb/in	1.25 lb/in	2.5 lb/in	5 lb/in	10 lb/in
CONSTANT		1.25	2.5	5	10	0.8 in	0.4 in	0.2 in	0.1 in	—			
Subject	ΔR %	—				—				—			
1	2												
	4												
	8												
	16												
	32												
2	2												
	4												
	8												
	16												
	32												
3	2												
	4												
	8												
	16												
	32												
4	2												
	4												
	8												
	16												
	32												

Note: Each block contains % correct of 20 discriminations.

Table 1

Experimental Design
Force Discrimination Tests

0.1 lb. Lateral

Variable Treatment		$\frac{\Delta\delta}{\delta}$			$\frac{\Delta K}{K}$			$\frac{\Delta K}{K}$ No Stop		
REFERENCE R		0.4 in	0.2 in	0.1 in	0.25 lb/in	0.5 lb/in	1.0 lb/in	0.25 lb/in	0.50 lb/in	1.0 lb/in
CONSTANT		0.25 lb/in	0.5 lb/in	1.0 lb/in	0.4 in	0.2 in	0.1 in			
Subject	ΔR %									
1	2									
	4									
	8									
	16									
	32									
2	2									
	4									
	8									
	16									
	32									
3	2									
	4									
	8									
	16									
	32									

Note: Each block contains % correct of 20 discriminations.

by an amount $\Delta\delta$ such that

$$C = K(\delta + \Delta\delta).$$

After a series of twenty random comparisons at a given R ($\Delta\delta$ in the $\frac{\Delta\delta}{\delta}$ Variable Treatments) in which the subject was forced to decide whether the C was a higher or lower force than R, the ΔR was changed and the series of twenty comparisons were repeated. Generally five ΔR were used for every level of CONSTANT. and there were four levels of CONSTANT (K in $\frac{\Delta\delta}{\delta}$ Variable Treatments) for every Variable Treatment $\frac{\Delta\delta}{\delta}$.

In the $\frac{\Delta K}{K}$ Variable Treatments, see Table 1, the ΔR was derived from maintaining the δ (deflection micrometer setting) at a CONSTANT level and varying the REFERENCE K by an amount ΔK such that

$$C = \delta(K + \Delta K).$$

Again the subject was given a series of twenty random comparisons at a given ΔR (ΔK in the $\frac{\Delta K}{K}$ Variable Treatment) in which he was forced to decide whether the C was a higher or lower force than R. Then the ΔR was changed and the series of twenty comparisons were repeated. Generally five ΔR were used for every level of CONSTANT and there were four levels of CONSTANT (δ in $\frac{\Delta K}{K}$ Variable Treatments) for every Variable Treatment $\frac{\Delta K}{K}$.

A third set of Variable Treatments $\frac{\Delta K}{K}$ was added to the force discrimination test, in which there was no constant δ; the subject pushed as hard as he wanted. This set was a control

to test whether the results of the $\frac{\Delta K}{K}$ Variable Treatment with CONSTANT δ were due to the variation in force or the variation in K.

The entire test was conducted at three different force levels:

1. 10 lb. compression
2. 1 lb. compression
3. 0.1 lb. lateral.

In the compression tests, the cane was grasped as in Fig. 3 and the cane was pushed into the variable spring socket until the socket came down against the deflection micrometer stop. At that point the subject felt the R or C stimulus. The time span between feeling R and feeling C was $0.5 < T < 1$ seconds. Not only were the two compression force tests separated by an order of magnitude in force level, but the CONSTANTS generally spanned an order of magnitude. See Table 1.

In the lateral force test, the force level was calculated to be 0.1 lb. assuming an average coefficient of friction of 0.4 and a pavement reaction force on the cane ferrule of 0.25 lb. This force level was subjectively verified by Mr. John Dupress, Technological Director, American Foundation for the Blind. The compression test force levels of 10 lb. and 1 lb. were estimated on the basis of the traverse observations.

Fig. 4 illustrates the stance and grasp used in the lateral force test. It is of interest to note that subjects' wrists tired after about 15 minutes of lateral tests at which time the

LATERAL
FORCE
DISCRIMINATION

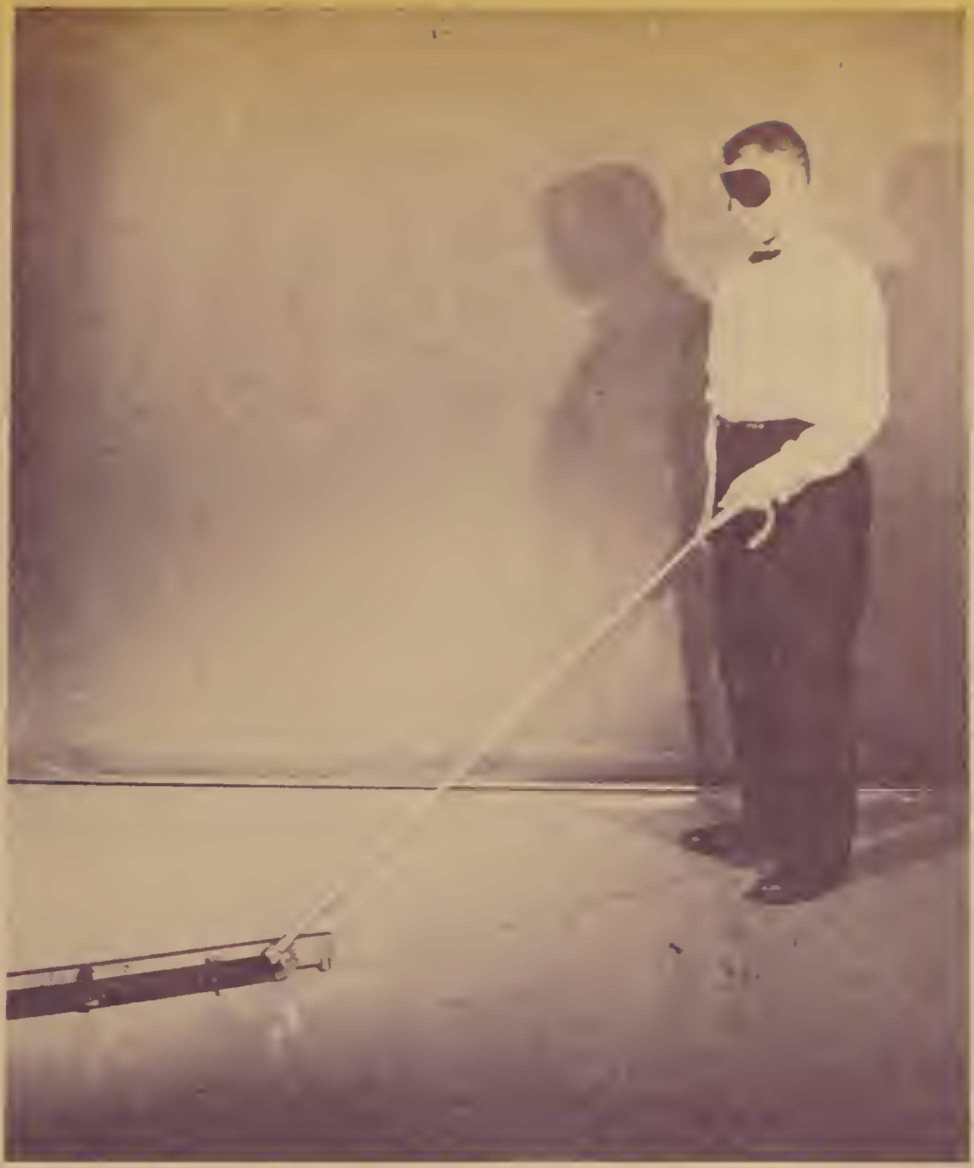


FIG. 4

COMPRESSION
FORCE
DISCRIMINATION

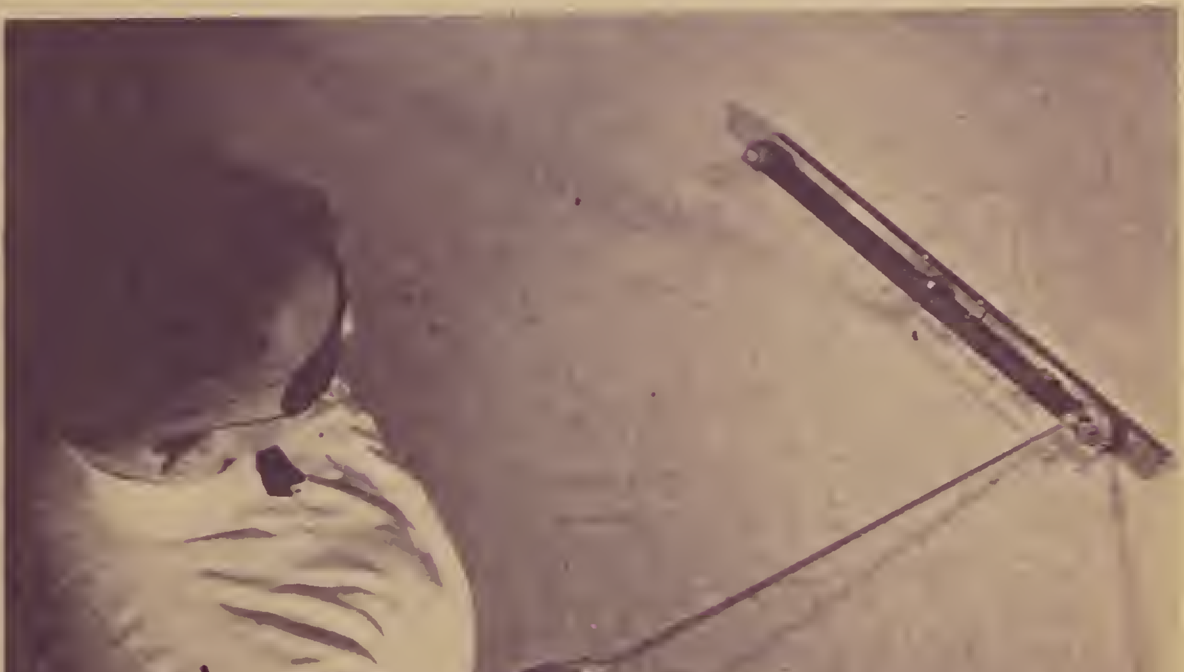


FIG. 3

lateral degree of freedom grasp, as in Fig. 1, was used for lateral cane motion. A series of tests revealed no significant difference between the two grasps with respect to force differentiation. Naturally, in the lateral tests the subjects exerted no compression pressure on the cane handle, just a lateral sweeping type motion.

Four subjects were used in the compression tests while three were used in the lateral tests. All subjects were M.I.T. students, age 19 to 23, of normal appearance and physique. Two of the subjects were left-handed. Blindfolds were used in all tests. Prior to each series of twenty comparisons the subject was allowed sufficient cane presses against the spring to eliminate any learning curve bias. The design of the test was a Treatment X Subject experiment wherein every subject underwent every treatment. Some fatigue undoubtedly appeared but the order of CONSTANTS was randomized to neutralize the fatigue effect. The method of computing the jnd's is described in Appendix A.

It was extremely difficult to make any hypotheses in the beginning since no work had been done in this area previously, and the conclusions of the aircraft control experimenters (20,21,22,23) are inconsistent to the point of direct opposition, in some cases, with reference to force and displacement proprioceptive feedback from spring-loaded stick forces.

Displacement Discrimination Test

The displacement tests were designed for simplicity and

reliability. The fractionation method of psychophysics was used since "halving is a wonderfully simple psychological operation" (3) which is used continually by the blind in aligning themselves for street crossing, stair traverses, and moving in narrow passages.

In this test the subjects performed two orthogonal fractionations. The first consisted of a blindfolded subject sweeping his cane across the floor in front of him from an approximate straight ahead position, in an arc first to a stop on his left front, then 24 in. to a stop on his right front and then splitting the 24 in. sweep by stopping his cane at a point he felt was half way in-between the right and left stop. Errors were tabulated in the conventional positioning-error psychophysical method. Twelve subjects were used, half of whom shifted their position after each of the forty determinations made for the lateral axis. The orthogonal fractionation, see Fig. 2, page 7, consisted of repeating the above test, i.e. splitting a 24 in. sweep, except that the depth axis (forward from the subject) was used. The subject moved his cane along the floor between two stops on his fore-and-aft path directly in front of him. The distance again was 24 in. and again half of the twelve subjects shifted position after each of forty determinations. The constant error - mean distance from center, and the variable error - standard deviation of the distances from

center - were computed for both axes.

In the fractionation tests, the floor was covered with paper for homogeneity of surface. Subjects reported no cues other than the stops themselves.

TEST APPARATUS

Subjects

All subjects were male, M.I.T. students, ages 19 to 23. None were in any way unusual and their performance curves were in no way indicative of subject trend. Indeed the sample was as homogeneous as an experimenter could expect. None of the subjects in the force and displacement tests were blind since it was felt that the use of blind subjects for 20 one-hour sessions apiece could provide non-technical difficulties that exceeded the experimental problems. Furthermore, there appeared to be no particular advantage in using blind subjects where differences of background and length of blindness might grossly bias the results.

The displacement test subjects were not paid, the others were hourly paid. Subjects, in general, were quick to report experimental technique anomalies and were very helpful in suggesting solutions - some of which were used.

Test Specimen

The long canes used were manufactured by the Mah-zell Co. of Brooklyn, N.Y. Test specimens weighed $\frac{1}{2}$ lb., were 55 in. long, 0.5 in. O.D., duraluminum tubing, 0.050 in. thick, and had a replaceable steel ferrule with rubber washer sound dampener.

The longitudinal spring constant of this cane is 225 lb./in. while the lateral spring constant is 0.5 lb/in. assuming that the

cane is rigidly grasped at the handle, and the input force is applied at the ferrule.

These canes are identical to those used in two blind training centers in the Boston area. The canes are available to the blind at a cost of about $2.

Variable K Spring and Deflection Micrometer

The variable K spring, Fig. 5, is an ordinary cantilever construction with a sliding block knife-edge which serves to vary the spring constant as a function of the block distance from the tip of the leaf. There are three leaves, one for each force test, and leaves vary from $\frac{1}{4}$ in. thick ($10 < K < 360$ lb/in.) to $\frac{1}{16}$ in. thick ($0.12 < K < 4$ lb/in.). Each leaf can mount either a compression socket, as in Fig. 5, or a lateral socket, as in Fig. 4.

The deflection micrometer is a closely fitted $\frac{3}{4}''$ x 10 N.C. steel lead screw and disc. The disc is graduated to 0.005 in. and is easily adjustable to 0.001 in.

Calibration of the three leaves was done by precise dead-weight loading and micrometer measurement of δ for each $\frac{1}{2}$ in. of movement of the sliding block knife-edge. The calibration curves were fairly smooth cubics.

For the compression mode, the spring base - a 2 in. angle iron - was floor mounted and gave the cane a 45° address. For the lateral mode, the spring lay at a 10° angle to the floor in

order to use the very slight gravity component for preloading the spring by enough force to keep it in contact with the sliding block.

VARIABLE K SPRING AND DEFLECTION MICROMETER

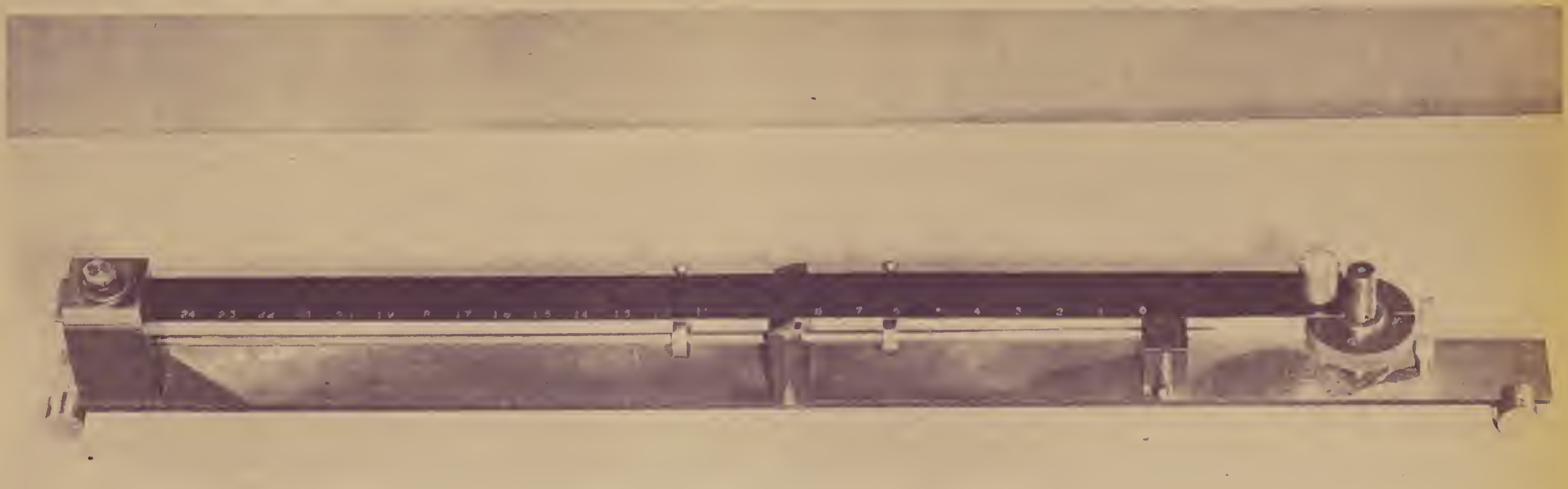
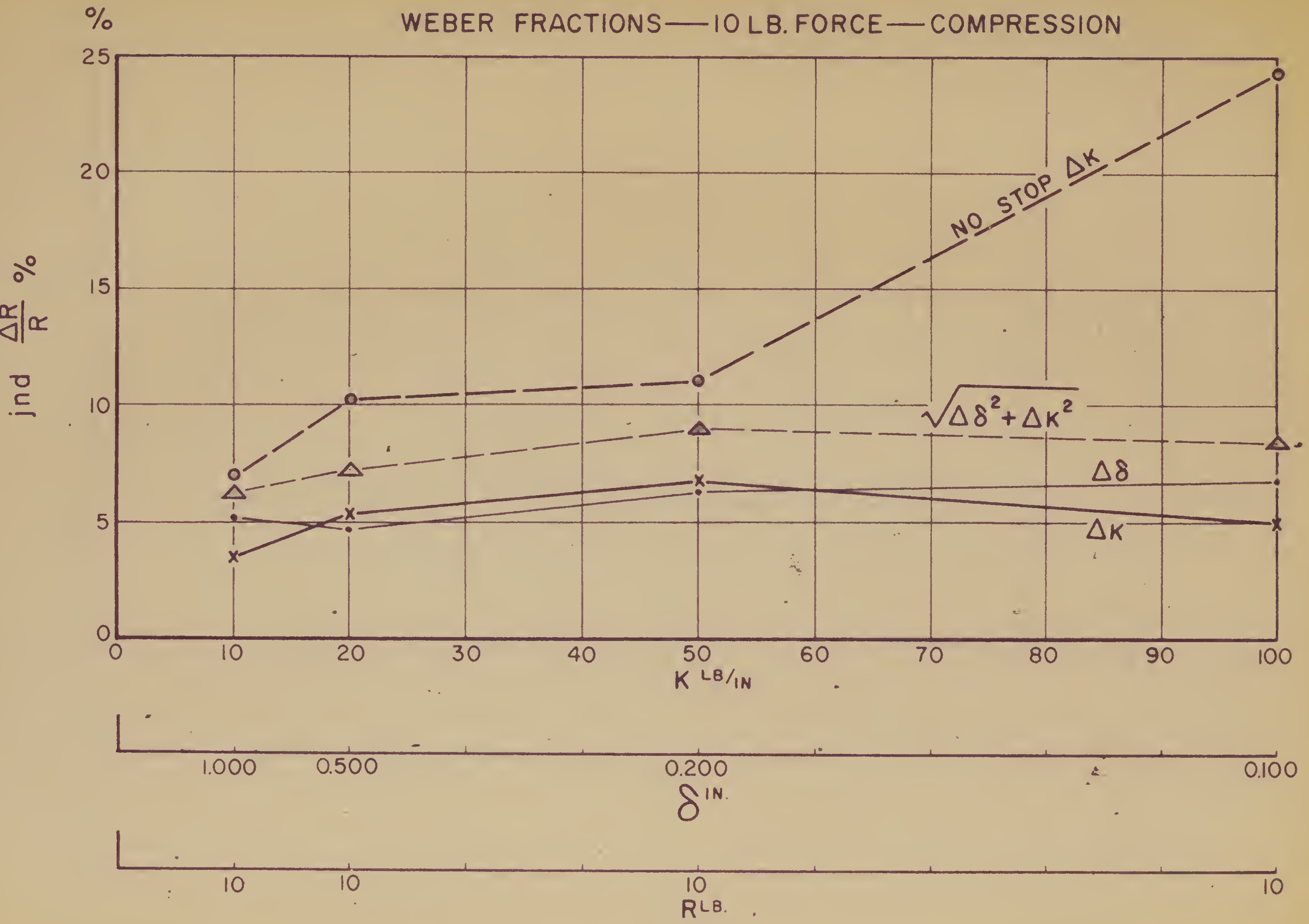


FIG. 5



WEBER FRACTIONS——10 LB. FORCE——COMPRESSION

FIG. 6

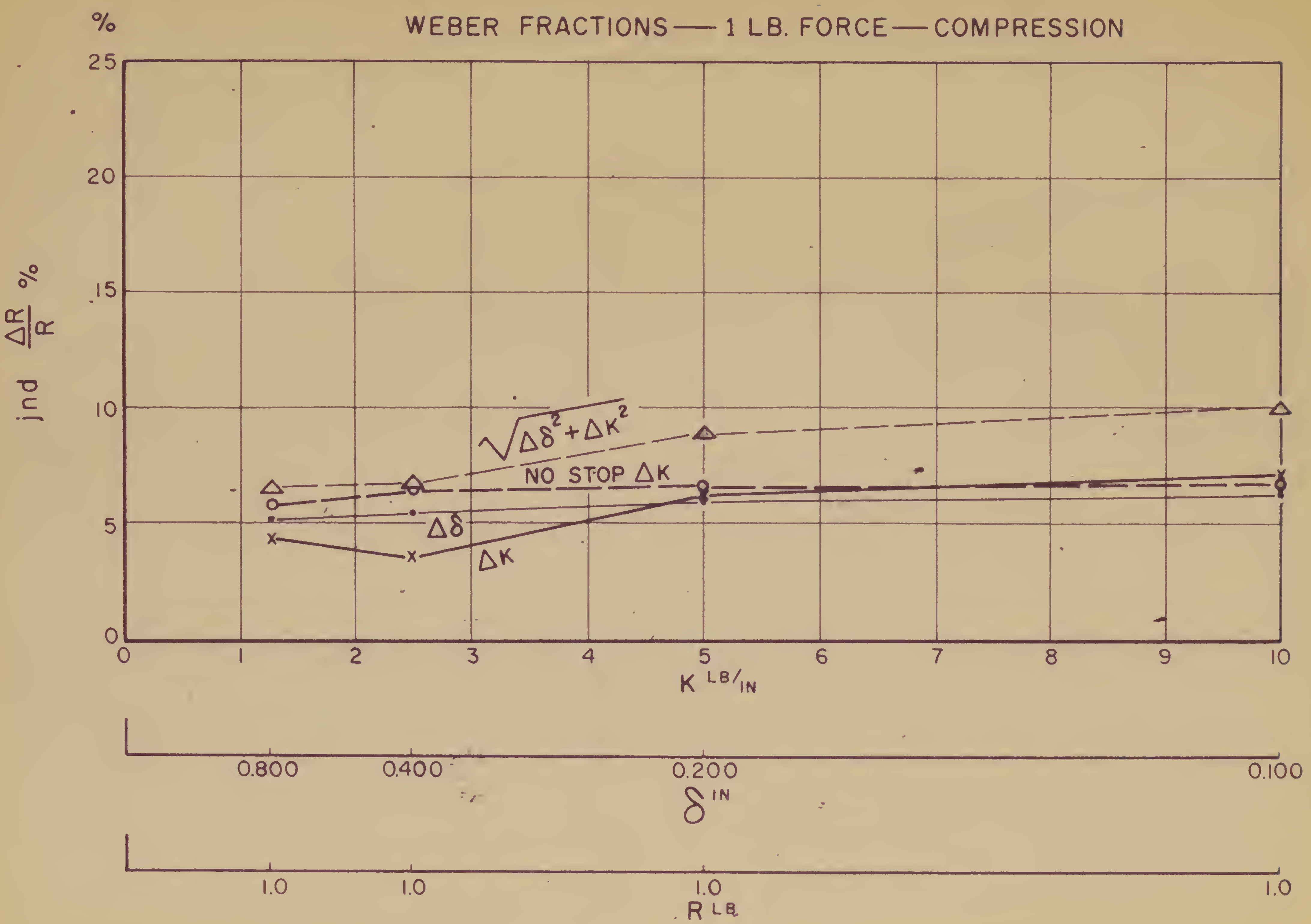

WEBER FRACTIONS — 1 LB. FORCE — COMPRESSION
%
25
20
15
10
5
0
jnd $\frac{\Delta R}{R}$ %
$\sqrt{\Delta\delta^2+\Delta K^2}$
NO STOP ΔK
Δδ
ΔK
0
1
2
3
4
5
6
7
8
9
10
K LB/IN
0.800
0.400
0.200
0.100
δ IN
1.0
1.0
1.0
1.0
R LB

FIG. 7

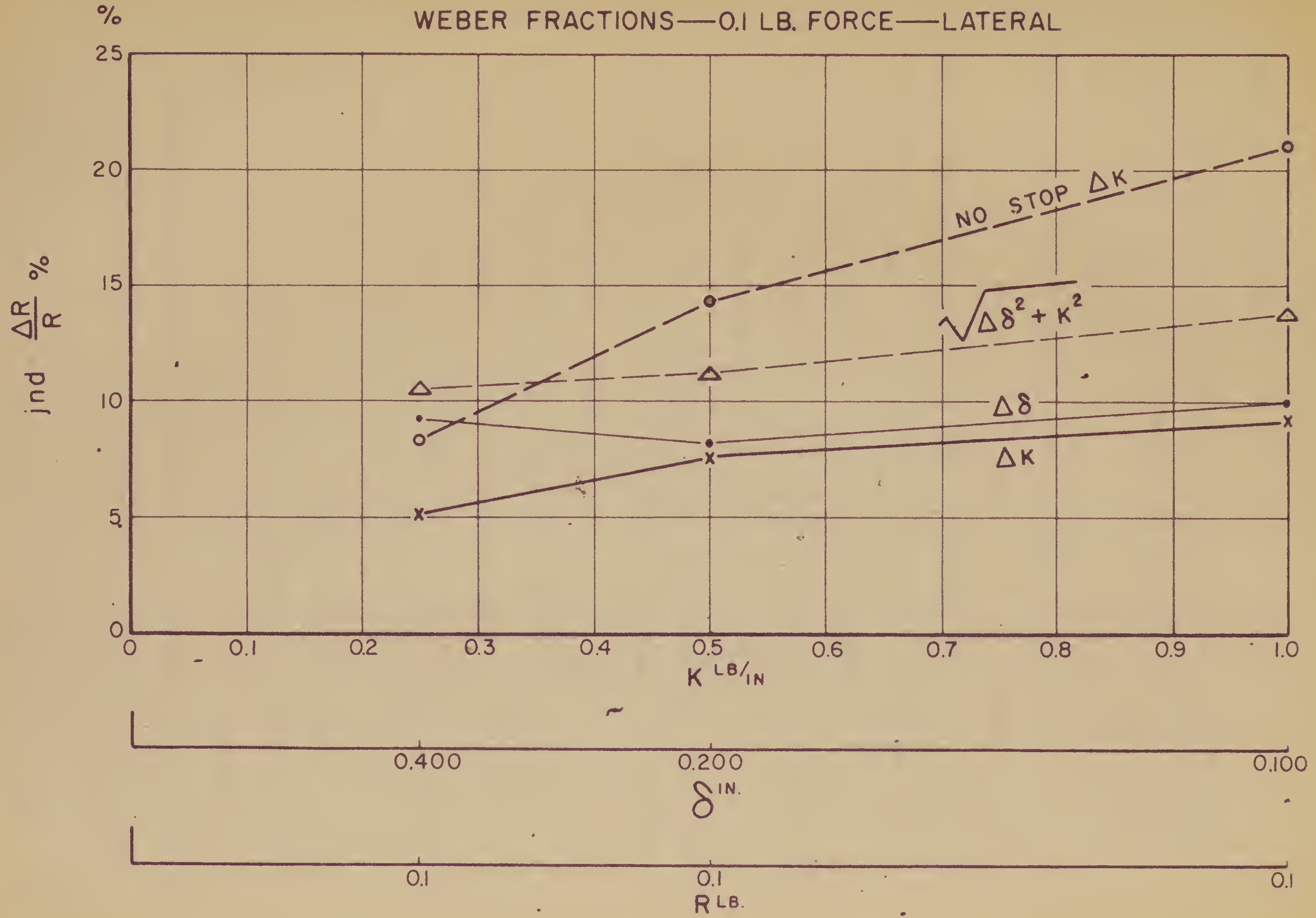

WEBER FRACTIONS—0.1 LB. FORCE—LATERAL

FIG. 8

EXPERIMENTAL RESULTS

Force Test Discussion

The force discrimination test data is quite lengthly since it represents over 12,000 discrete force discriminations. The results are tabulated in Table 2, pages 28-30, and are plotted on the three Weber Fraction Graphs, Figs. 6, 7 and 8.

Each Weber Fraction Graph contains the differential limen of all subjects for each variable treatment, $\frac{\Delta R}{R}$. The abscissa Variable is plotted as K with its respective complement δ beneath it. The abscissa R could have been plotted as δ with its complement K beneath it. In any case the product of the Variable with its complement must always equal the reference force level R of the test. Note, however, that the Weber Fraction Graphs do not plot $\frac{\Delta R}{R}$ versus R since the force R of each graph is a constant.

A Weber Fraction curve could be constructed from the three force test averages to show $\frac{\Delta R}{R}$ versus R by taking the mean differential limen of all jnd's in the constant K and constant δ treatments of each R force level. This would require making an assumption that the lateral force discrimination treatments were from the same population as the compression force tests. There is no evidence or basis for such an assumption. There is good basis, however, for averaging the constant δ and constant K treatments together since statistical significance tests indicate no significant population difference between the force discriminations made in the variable δ (constant K) treatments and the variable K (constant δ) treatments for a given force level.

Table 2

Experimental Results

Force Discrimination 10 lb. Compression

Variable Treatment $\frac{\Delta \delta}{\delta}$			Variable Treatment $\frac{\Delta K}{K}$			Control Treatment $\frac{\Delta K}{K}$ NoStop		Possible Interaction of Variable Treatments	
CONSTANT K lb/in	REFERENCE δ in.	$\overline{jnd}$ %	CONSTANT δ in.	REFERENCE K lb/in	$\overline{jnd}_K$ %	REFERENCE K lb/in	$\overline{jnd}$ %	$\sqrt{\overline{jnd}^2 + \overline{jnd}_K^2}$ %	
10.0	1.000	5.08	1.000	10.0	3.48	10.0	7.00		6.15
20.0	0.500	4.75	0.500	20.0	5.34	20.0	10.29		7.15
50.0	0.200	6.06	0.200	50.0	6.41	50.0	11.20		8.82
100.0	0.100	6.85	0.100	100.0	5.05	100.0	24.42		8.51
	$\overline{\overline{jnd}}$	5.69		$\overline{\overline{jnd}}$	5.07	$\overline{\overline{jnd}}$	13.20		
	SD	0.95		SD	1.21	SD	7.69		

$CR_{(\text{Variable Treatments})} = 0.81$

$CR_{(\frac{\Delta K}{K} \text{ Treatments})} = 2.10$

Explanation of Terms

$\overline{jnd}$ = jnd's averaged across subjects at each CONSTANT level

$\overline{\overline{jnd}}$ = Sample Mean jnd for each treatment = $\frac{\sum \overline{jnd}}{N}$, where N = number of $\overline{jnd}$'s = 4

SD = Sample Standard Deviation = $\frac{\sqrt{(\overline{jnd} - \overline{\overline{jnd}})^2}}{N - 1}$

σ_x = Standard error of the Sample Mean = $\frac{SD}{\sqrt{N}}$

CR = Critical Ratio of the difference in Sample Means = $\left[\frac{\overline{\overline{jnd}}_1 - \overline{\overline{jnd}}_2}{\sqrt{x_1^2 + x_2^2}}\right]$, and indicates a significant difference in Sample Means if CR > 1.96.

Table 2

Experimental Results

Force Discrimination 1 lb. Compression

Variable Treatment $\frac{\Delta\delta}{\delta}$			Variable Treatment $\frac{\Delta K}{K}$			Control $\frac{\Delta K}{K}$ Treatment NoStop		Possible Interaction of Variable Treatments
CONSTANT K lb/in	REFERENCE δ in.	$\overline{jnd}$ %	CONSTANT δ in.	REFERENCE K lb/in	$\overline{jnd}_K$ %	REFERENCE K lb/in	$\overline{jnd}_K$ %	$\sqrt{\overline{jnd}_\delta^2 + \overline{jnd}_K^2}$ - %
1.25	0.800	5.31	0.800	1.25	4.53	1.25	5.87	6.98
2.50	0.400	5.80	0.400	2.50	3.47	2.50	6.55	6.75
5.00	0.200	6.28	0.200	5.00	6.48	5.00	6.79	9.02
10.00	0.100	6.82	0.100	10.00	7.60	10.00	6.76	10.21
	$\overline{\overline{jnd}}$	6.05		$\overline{\overline{jnd}}$	5.52	$\overline{\overline{jnd}}$	6.50	
	SD	0.65		SD	1.42	SD	0.43	

$CR_{(\text{Variable Treatments})} = 0.68$

$CR_{(\frac{\Delta K}{K}\text{ Treatments})} = 1.32$

See page 28 for explanation of terms.

Table 2

Experimental Results

Force Discrimination 0.1 lb. Lateral

Variable Treatment $\frac{\Delta \delta}{\delta}$			Variable Treatment $\frac{\Delta K}{K}$			Control Treatment $\frac{\Delta K}{K}$ NoStop		Possible Interaction of Variable Treatments
CONSTANT K lb/in	REFERENCE δ in.	$\overline{jnd}$ %	CONSTANT δ in.	REFERENCE K lb/in	$\overline{jnd}_K$ %	REFERENCE K lb/in	$\overline{jnd}$ %	$\sqrt{\overline{jnd}_\delta^2 + \overline{jnd}_K^2}$ %
0.25	0.400	9.09	0.400	0.25	5.16	0.25	8.37	10.42
0.50	0.200	8.17	0.200	0.50	7.89	0.50	14.17	11.34
1.00	0.100	10.09	0.100	1.00	9.41	1.00	21.13	13.80
	$\overline{\overline{jnd}}$	9.12		$\overline{\overline{jnd}}$	7.49	$\overline{\overline{jnd}}$	14.56	
	SD	0.96		SD	2.15	SD	6.38	
$CR_{(\text{Variable Treatments})} = 1.20$				$CR_{(\frac{\Delta K}{K}\ \text{Treatments})} = 1.82$				

See page 28 for explanation of terms.

Note: N = 3 in the above test.

This does not include the data from the control test (variable K, no stop).

Clearly, it appears that when the cane is used to make compression force discriminations, the blind man is capable of detecting force differences of 5.4% at the 10 lb. force level and 5.8% at the 1 lb. level. In addition, it doesn't matter whether the increment of force is derived from an increase in K or an increase in δ over a range of $1 < K < 100$ lb./in. and $0.1 < \delta < 1.0$ in. A cautious reminder is that the canes used to obtain these conclusions had a longitudinal spring constant of 225 lb./in. and a lateral spring constant of 0.5 lb./in. For lateral forces of 0.1 lb. the data indicates a mean differential limen of 8.3%.

One experimenter (22) obtained remarkable agreement when measuring differential limen in positioning a spring loaded control stick. He indicated 6% differential limen between forces of 1 lb. and 10 lb. with higher thresholds at force levels below 1 lb. One possible explanation for the rise in thresholds as the lower force levels are approached, is that the intensitive threshold of a man is being approached and, as has been shown countless times in all standard experimental psychology books, the Weber fraction is not a constant at low intensity ranges but rises sharply in the area of the lowest level of intensity that man can detect.

The control treatment is not, strictly speaking, part of the force discrimination test since the test spring could be

depressed to any δ , and therefore any force, that the subject desired. This treatment was used, in addition to its control function in the design, to test a hypothesis that the cane user could readily discriminate changes in spring constant without any reference to a definite force level obtained by limiting the deflection to a definite δ. The data of the control treatment in the 1 lb. compression test would seem to bear this out, but the control treatment in the 10 lb. compression and 0.1 lb. lateral test indicate a definite reduction in K discrimination.

One immediately observes, see Table 2, that in the 1 lb. compression test, the spring constant of the cane far exceeds that of the test spring, by more than an order of magnitude while in the other two tests the spring constants are not so widely separated. Therefore, in effect, the cane is an infinitely stiff spring in this particular 1.0 lb. force man-cane-environment system, and the effective stiffness of the system approaches the stiffness of the test spring.

In the control treatment, when the cane is effectively an infinitely stiff spring, the discrimination process is simplified since for all practical purposes the cane does not deflect at all and the subject simply had to: make a subjective estimate of the deflection of his reference motion; try to duplicate this deflection in his comparison motion; then judge which of the two motions produced the heavier force. Of course, one may take the reciprocal approach, i.e., the subject estimates the reference force which he

has produced - it can be any value; pushes the cane down for the comparison motion until he feels that the comparison force equals the reference force; then judges which deflection was the greater. However this reciprocal approach does not appear to be valid, for in the $\frac{\Delta\delta}{\delta}$ Variable Treatment (fixed K, variable δ) the differential limen observed was not significantly lower than the differential limen observed in the $\frac{\Delta K}{K}$ Variable Treatment when the force was incremented by a change of K instead of δ. In fact the $\Delta\delta$ jnd's were slightly higher, though not significantly. The inference is that the force discrimination of a man-cane system is not a function of K or δ alone but a combination of these variables.

If the aircraft control stick experimenters previous work can be used as a comparison, it may be noted that one source (21) indicates δ as the variable affecting positioning responses by proprioceptive feedback while another experimenter (23) takes the view that variations in K are the primary parameter changes affecting the man-machine response. Other works (19,20) develop the relationship between force and displacement as variables affecting position error, in flight control sticks, by a ratio: positioning error $\sim \frac{F\delta}{\Delta F}$. Now if $K = \frac{\Delta F}{\Delta\delta}$ we can restate the ratio as position error $\sim \frac{F}{K}$. The results of the control treatment tests (variables K, No-stop) tend to show agreement with this relationship.

When the test spring stiffness approaches to within about

50% of the cane stiffness, the springs-in-series effect reduces the increment of the effective spring constant of the cane-test spring system. See Appendix B. Hence the 1 lb. compression control tests showed much better K discrimination since the highest test spring K used in that test was 4% of the cane K.

Also, it was observed that during 10 lb. and 0.1 lb. control tests, the subjects almost invariably pushed on the cane with a greater force than the reference force of the two fixed force treatments; e.g. in the 10 lb. compression force tests, the subjects pushed on the cane with forces up to 100 lb. during the control treatments - $\frac{\Delta K}{K}$ No-stop, and the canes flexed a great deal. This high force coupled with the reduced effective increment, $\Delta K'$, of the cane-spring system gave a high $\frac{F}{K}$ ratio which might account for the poor discrimination of compliance changes when cane K approaches spring K.

Another basis for explanation as to why compliance discrimination differed so much from force discrimination for the same level of K might be the possible interaction of the differential limen of the variable δ treatment with that of the variable K, constant δ, treatment. The results are tabulated in Table 1 and are plotted with the Weber Fraction Graphs, Figs. 6, 7 and 8. The results are inconclusive.

Force Test Conclusions

The following may be said of the force correlate of the somesthetic stimuli through the blind man's conventional long

cane:

1. Force discrimination or resolution appears to be at about the 5 $\frac{1}{2}$ % differential level for forces between 1 lb. and 10 lb. along the compression axis of the cane.
2. The differential threshold of force discrimination appears to be higher, about 8 $\frac{1}{2}$ %, for a force of 0.1 lb. in the lateral axis.
3. The stiffness of the cane with respect to the environmental stiffness, does not significantly affect force discrimination. It does, however, affect compliance resolution when cane K approaches environmental K.

Displacement Test Discussion

	Lateral			Depth		
	CE in.	SD in.	CR	CE in.	SD in.	CR
Shift	-0.25 lt	1.34	2.89	-0.20 back	1.09	0.60
No-shift	+0.61 rt	1.19		-0.36 back	1.17	
CE = Constant Error; SD = Standard Deviation; CR = Critical Ratio						

Each of the four treatments was repeated 40 times by each subject and the statistics averaged across subjects. The two lateral treatments are significantly different at the 1% level while the depth treatments are not different.

The variability as indicated by the standard deviations shows remarkable uniformity considering the change from a

shifting stance to no-shifting between determinations. The variability is the parameter of greatest interest, and it indicates a measure of displacement resolution obtainable with the long cane. This resolution or differential threshold of distance discrimination is about 10% if the SD is divided by one-half of the total sweep, 24 in. Goldscheider (4) measured a discrimination of motion at the shoulder joint of about 20' of arc. This is considerably better than the variability obtained in this test using the long cane. The 1.2 in. average standard deviation at the maximum distance of six feet from shoulder to cane tip is about 1° of arc. Since there is only one other experiment to compare these results with, and that experiment did not use a cane, the best assumption is that the 10% distance threshold is a reasonable parameter in the man-cane distance discrimination system.

It might be noted that the 0.1 lb. lateral force average differential limen was 9.12% while the average lateral distance standard deviation was 10.5%. The similarity of threshold levels may be significant but it is difficult to show the correlation from this experiment.

Displacement Test Conclusions

The conclusion of interest in this test is:

1. The distance discrimination threshold for the blind using the long cane appears to be 10% for both lateral and depth fractionations. This threshold might be improved with practice.

Future Investigations

Since this is an initial attempt to study the mechanical interactions between a blind man and his environment through the medium of the cane, there are many areas of the problem yet to be explored.

Future investigations specifically connected with this study are numerous. A few are enumerated:

1. Determine whether higher threshold in the 0.1 lb. lateral force test was due to lower sensitivity of muscles used in the lateral axis or the extremely low force level, by
    a. Replication of the compression tests at the 0.1 lb. level and perhaps lower.
    b. Replication of the lateral test at the 1 lb. level and perhaps at the 0.05 lb. force level.
2. Determine the effect of surface differences on geometric discriminations with the long cane, in particular on fractionation. There is precedence for this work in the experimental psychology literature.
3. Determine the effect of time variations on geometric discriminations. The time correlate may be as significant as force or distance. Do the blind measure distance with the cane by timing the sweep? Would the introduction of acceleration or acceleration rate affect fractionation?
4. Study of time-variant force interactions transmitted by the cane, and determination of thresholds for various

treatments of impulses and vibration - sinusoidal and random, frequency spectrum 20 to 300 cps, amplitudes of 1 mm to 0.001 mm.

5. Determine thresholds of low level compression and lateral force discriminations and distance fractionations using the finger. Is the long cane really the equivalent of a digital extension as far as response to the correlates herein studied?

Application of Conclusions

This study was started to gain some insight in the kinesthetic and tactual stimuli transmitted by the cane. The ultimate use of this information, hopefully, will be to increase mobility for the blind.

The Technical Research Council (13) lists these requirements for a mobility aid:

1. Locate obstacles 10 to 12 ft. ahead, 25° right and left of path centerline, at a walking rate of 5 ft./sec.
2. Give step-down warning of drop-offs exceeding 2 in. at a distance of 6 to 8 ft.
3. Provide information transfer to the brain in a simple manner not requiring an excessive training period.
4. Must not be unduly conspicuous.
5. Perform reliably even in adverse weather.

In addition to this, Hoover (2), mentions the following convenience requirements for the cane:

1. Adjustable length.
2. Light weight and well balanced for reduction in sweeping

fatigue.

3. Comfortable handle.

4. Non-catching tip for both crevices and cracks.

One can assume that any research done with the cane ought to lead to either an improvement in the blind man-cane system performance and/or an increase in the convenience of use of the cane without system performance degradation. The latter view requires that some figure of merit for the performance of the cane-man system should be available to the designer so that optimizing the cane for convenience does not adversely affect the system performance based on these figures of merit.

The performance of the long cane used by the blind today satisfies almost all of the Technical Research Councils' requirements, above, reasonably well. The convenience requirements cited by Hoover, above, however, are only moderately satisfied by the long cane. It would also be well if the advantages of a longer cane could be had without the inherent hazards to other people of tripping and bruised shins which are caused by the present rather stiff cane. In addition it would be advantageous to have a cane that could be collapsed to pocket size and yet extendable to a length great enough to give obstacle warnings two paces ahead instead of the present one pace obtained with the long cane and Hoover technique.

All of the above conveniences are certainly within the capabilities of the designer - providing that they can be combined in a cane without affecting the performance parameters

adversely.

(It is not within the scope of this thesis to prove that the force and displacement discrimination levels found here are sufficient as well as necessary to define the performance characteristics of the cane. This would, at present, still be an assumption - certainly not perfect, but probably valid.)

Suppose, then, that in optimizing the cane for convenience, the designer becomes apprehensive about the ability of his cane to transmit the necessary stimuli to the blind man's kinesthetic and tactile senses because of an extremely low compression spring constant. It is relatively easy to determine what the threshold of the blind man is with the redesigned cane for any force level between 1 lb. and 10 lb. using a test spring of any stiffness from 1 lb./in. to 100 lb/in. If this threshold exceeds $5\frac{1}{2}$ % the designer has degraded the performance of the cane - at least for compression forces in the range of interest. By the same token, depth fractionation should also be compared to the 10% variability over a 24 in. arc found herein, for the possibility of the loss of depth distance perception with the new cane.

In the future, more parameters may be established which will more closely characterize the correlate transmittance of the cane; but for the present, this is the beginning.

APPENDIX A

jnd Computation Methods

Referring to the experimental design, Table 1, pp. 11-13, each blank represents the subject's score in % correct judgements, for each set of 20 comparisons. The scores for each ΔR or increment - 2%, 4%, 8%, 16%, 32% - were averaged across subjects by Treatment and Reference, e.g., the 2% $\Delta \delta$ increment scores of all subjects for the 10 LB compression force, Variable treatment (1.0 inch reference) test were averaged. This mean score, say 65% correct judgements, was then plotted as a point on probability scale paper. Then the 4% average score for the same test was plotted on the same paper. The remaining 3 increments, 8%, 16%, 32%, were also plotted and a least squares best fit straight line was drawn. The increment, ΔR at which this line crossed the 75% correct line was arbitrarily (24) called the differential limen (ΔR) or $\overline{\text{jnd}}$ at which a man with a cane could just notice a difference between δ_{REF} and $\delta_{REF} + \Delta \delta$.

The use of probability scale paper was made for this computation since a normal distribution ogive function, which is typical of most thresholds, determined by this frequency method of psychophysics (24), plots as a straight line on probability paper.

Referring to the experimental results, Table 2, pp. 28-30, the $\overline{\text{jnd}}$'s were then averaged across treatments and students "t"

test applied. The explanation of terms in Table 2 indicates statistical methods used.

In plotting the average scores on probability paper, only those averages less than 100% correct judgements were plotted since the 100% ordinate, on probability paper, is of infinite height.

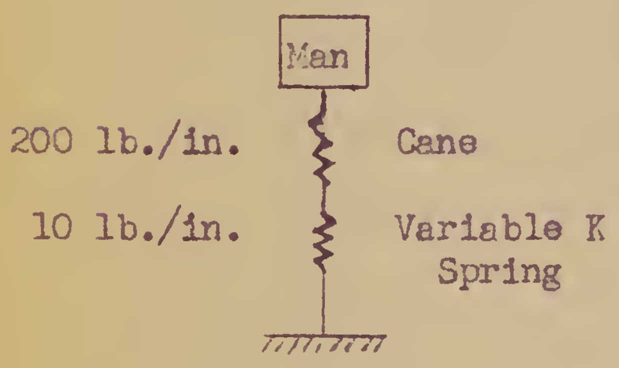
APPENDIX B

Springs-in-Series Effect

It can be shown that though one varies the K of the test spring by a specified increment, say 10%, the effective change in the K of the cane-spring system may not change by that amount unless the K of the spring is much less that the K of the cane.

Consider the following spring systems:

Fig. a



System Reference Condition:

$$K_R = \frac{200 \times 10}{200 + 10} = \underline{9.5} \text{ lb/in.}$$

System Comparison Condition for a △ K = 10%:

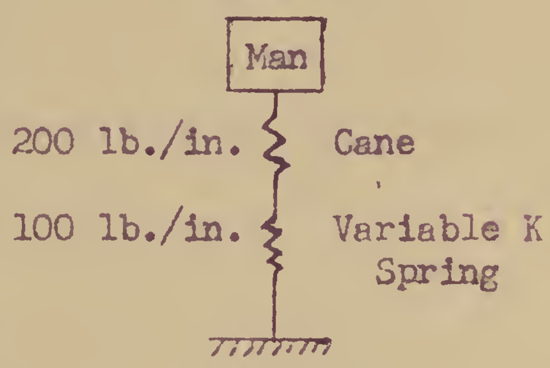
$$K_C = \frac{200 \times 11}{200 + 11} = \underline{10.4} \text{ lb/in.}$$

$$K_C - K_R = 10.4 - 9.5 = 0.90 \text{ lb./in.}$$

$$\frac{K_C - K_R}{K_R} = \frac{0.90}{9.5} = 9.5\%$$

∴ System Change = $\underline{9.5\%}$ for a △ K = 10%

Fig. b



System Reference Condition:

$$K_R = \frac{200 \times 100}{200 + 100} = 66.7 \text{ lb./in.}$$

System Comparison Condition for a △ K = 10%:

$$K_C = \frac{200 \times 110}{200 + 110} = 70.9 \text{ lb./in.}$$

$$K_C - K_R = 70.9 - 66.7 = 4.2 \text{ lb./in.}$$

$$\frac{K_C - K_R}{K_R} = \frac{4.2}{66.7} = 6.3\%$$

∴ System Change = $\underline{6.3\%}$ for a △ K = 10%

APPENDIX C

Distance Discrimination Computation Methods

The method employed in reporting the results of the displacement discrimination test was as follows:

1. x = the distance that each of the 40 determinations per subject per treatment (e.g. Lateral-Shift) missed the center of the arc.
2. $\bar{x}$ = mean miss per subject per treatment
   $= \frac{\sum x}{n}$, where $n = 40$
3. σ = standard deviation of the misses per subject per treatment
   $= \frac{(\bar{x} - x)}{n}$
4. CE= Constant Error for all 6 subjects across each treatment (e.g. Depth No-Shift)
   $= \frac{\sum \bar{x}}{N}$, where N = number of subjects per treatment = 6
5. SD= Variability or mean standard deviation for all 6 subjects across each treatment
   $= \frac{\sum \sigma}{N}$
6. CR= Critical Ratio of the difference in the CE's of the Shift and No-Shift treatments by axis
   $$= \frac{CE_{shift} - CE_{no\text{-}shift}}{\sqrt{SD^2_{x_{shift}} + SD^2_{x_{no\text{-}shift}}}}$$
7. SD_x = Standard Error of the sample mean
   $= \frac{SD}{\sqrt{N}}$

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